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2. MOLDAVITES

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2. MOLDAVITES

(Following is the translation of an article by G. G. Vorob'yev in Meteoritika (Meteoritics), No 18, 1960, 35-40)

In the České Budějovice region of Czechoslovakia along the banks of the Vltava river (old name - Mldava) since the eighteenth century unusual forms of green glass fragments have been found in the ground that have received the name of "pseudochrysolites", "Bohemian chrysolites", and "moldavites". More than ten thousand have been found in an area 150 km in length and 34 km in width (1). Some of them have been cut and used as semiprecious stones. At one time they had been carefully put into collections, until Professor Makovský at Brno suggested that they were only the products of ancient glass production. Later, however, similar glasses began to be found in Tasmania ("Darwin glass" and "tasmanites"), in Australia ("australites"), on Billiton Island ("billitonites"), in the Philippines ("philippinites" or "rizalites"), in Indochina ("indochinites"), in Africa ("Libyan glass"), and in certain regions of South America ("americanites"). All have received the general appellation "tektites" (2), and serious attention has begun to be directed to the question of their formation.

Since tektites have been known for a long time, they have been investigated more thoroughly. As early as 1932 the Czech scientist Novaček collected 22 chemical analyses of moldavites (four carried out by himself) (3). In 1914 Suess discovered traces of Li and Sr in a moldavite from Skreje-Dukovany (in Moravia) (4), and in 1929 Lacroix (5) wrote about the presence of Rb in many tektites. In the period 1932-1935 several works appeared on the microelements in tektites (Goldschmidt and colleagues (6 and others), Hevesy and Würstlin (7), Preuss (8,9) et al.). These works discovered in moldavites (in %):

Li_2O	—	0,003	ScO	—	0,0004
ZrO	—	0,011—0,016	Cr_2O_3	—	0,01
SrO	—	0,008—0,013	NiO	—	0,002
BeO	—	0,0005	B_2O_3	—	0,003

Considerably later (1949) D. P. Malyuga with the polarographic method found 0.0064% of Co in moldavite (10).

Since interest in tektites has greatly grown in recent times and lively discussions are being held on their origin, the author undertook an investigation of the composition of moldavites on the basis of the modern spectrographic method.[1]

Taking advantage of the opportunity presented, the author again expresses his thanks to the scientific secretary of the Committee on Meteorites AS USSR, Ye. L. Krinov, as well as to colleagues at the Committee L. G. Kvash, A. A. Yavnel', and M. A. Kozlovaya for all possible assistance and valuable advice.

Description of the Samples

The meteorite collection of the USSR Academy of Sciences has 146 samples of moldavites. Most of them were sent directly from Czechoslovakia (Bohemia and Moravia) from Frič in 1909 and Hanus in 1929, from the Mineralogical Museum of the East Siberian Institute in Irkutsk (date unknown), the Moravian Earth Museum (Moravské Zemské Museum) through Academician V. I. Vernadskiy in 1926.

For the spectral analysis samples were chosen from nine specimens: stock No 589 (place of find unknown), No 889 from Lhenice (Elhenitz), No 907 from Trebanice, No 992, 962, and 971 from Dolni Chrá-Stany (Untergroschum), No 1011 and 1023 from the area near Netolic. The first specimen came from the collection of B. Fisher, the rest from engineer Hanus (Prague). Two test specimens were taken from a single sample with the purpose of establishing variations in the composition in the largest part of the moldavite.

The weight of the samples in the collection varies from 0.53 to 53.15 g. The form of the samples is chiefly spherical, teardrop, finger-shaped, at times with elements of spiral twisting, but less clearly defined than is in the case of indochinites; there are many formless fragments, part of which are fragments of large hollow spheres. The color is bottle-green of various shades and is lighter than that of indochinites, with a dull shine, softened by natural polishing. Almost all of the samples have good piezoglyptic sculpture.

In fine fragments (to tenths of a millimeter) moldavites are colorless, slightly green or smokey (stock No 589, 919, 924, and 1023 are more green, while No 971 and 1011 are more smokey), at times with a weak sky blue or yellow shape. In almost all samples vesicle distribution is irregular from $n \cdot 10^{-3}$ to 0.2 - 0.3 mm, very often oval shaped.

In the first report (11) the presence was noted in indochinites of globules ranging in size from tenths of a micron to 10μ, which may be inclusions of foreign bodies (like plessite in silica-glass from Vabara(?) and Henbry(?)) or syngenetic spherolites - the centers of primary crystallization of an amorphous substance. After an exhaustive study of moldavite powder samples under the EM-100 electron microscope (magnification x-5000) only one small sphere of quite regular form and a diameter of 2μ was detected.

1. In the first report (11) analyses of six indochinites were published. In the future rizalites, tasmanites, libites, and other silica-glasses will be analyzed, as well as terrestrial rocks of the

obsidian variety that are similar in structure. On the basis of the first two reports a paper, "Microelements and the Problem of the Origin of Tektites", was given at the Eighth All-Union Meteorite Conference.

Special Analysis

The method of complete quantitative analysis of silicates, developed by the author, was described in the first report. With the purpose of making an additional check of the accuracy and of obtaining new data on individual components sample with stock No 924 was subjected to a chemical silicate analysis (analysist I. S. Losev). A comparative table of the two analyses is given below (Table 1).

The values for MnO and CaO yield the greatest discrepancies. In the first instance spectral analysis, ensuring accuracy up to the third digit after the decimal point, is most reliable. In regard to CaO spectral analysis was, apparently, less accurate. The mean deviation is 5% of the relative value. Averaged values for the two analyses can be considered completely reliable, taking into attention the sum obtained.

Comparative Chemical and Spectral Analysis of Moldavite (No 924) in %

	spectral analysis	chemical analysis	abs.	rel.	mean
SiO_2	80,1 *	80,31	+0,4	+0,3	80,21
TiO_2	0,57	0,60	+0,03	+5,2	0,58
ZrO_2	0,035	—	—	—	0,04
Al_2O_3	9,8	9,62	—0,2	—2,0	9,71
Fe_2O_3	—	0,27	—	—	0,27
FeO	—	1,42	—	—	1,42
ΣFeO	1,7	1,72	0	0	1,72
MnO	0,080	0,07	—0,01	—14,3	0,07
MgO	1,11	1,10	—0,01	—0,9	1,11
CaO	2,08	1,88	—0,16	—10,6	1,98
BaO	0,29	—	—	—	0,29
SrO	0,04	—	—	—	0,04
Na_2O	0,35	0,37	+0,02	+5,7	0,36
K_2O	—	3,65	—	—	3,65
H_2O^+	—	0,13	—	—	0,03
other H_2O^-	—	0,03	—	—	0,03
Прочие	0,018	—	—	—	0,02
Сумма . . . . . sum	100,0	99,45	—	—	99,81

*by difference (taking into account K_2O and H_2O.)

Table 2

Results of Spectral Analysis of Moldavites

No elements mean

№ п/п	Элементы	№ 589	№ 889	№ 907	№ 919—1	№ 919—2	№ 924	№ 962	№ 971	№ 1011	№ 1023	Среднее
1	Al	5,0	5,2	5,1	4,3	4,3	4,8	4,2	4,2	6,1	5,0	4,8
2	Ca	1,5	1,5	1,5	1,2	1,4	1,5	1,9	1,5	1,15	1,8	1,5
3	Fe	1,6	1,9	2,2	1,65	1,5	1,3	0,68	1,15	1,65	0,89	1,45
4	Mg	1,3	0,82	1,0	1,3	1,15	0,68	0,90	0,52	1,0	1,6	1,03
5	Ba	0,42	0,32	0,29	0,35	0,30	0,26	0,34	0,29	0,77	0,30	0,36
6	Ti	0,30	0,24	0,30	0,24	0,22	0,34	0,20	0,50	0,22	1,1	0,37
7	Na	0,36	0,26	0,36	0,33	0,35	0,26	0,17	0,30	0,32	0,21	0,30
8	Mn	0,090	0,068	0,073	0,088	0,11	0,062	0,086	0,033	0,047	0,11	0,077
9	Sr	0,1	0,07	0,08	0,07	Не опр.	0,03	0,06	0,04	0,05	0,06	0,06
10	Zr	0,041	0,026	0,031	0,024	0,021	0,026	0,026	0,026	0,018	0,022	0,026
11	V	0,0039	0,0037	0,0040	0,0033	0,0028	0,0026	0,0018	0,0028	0,0041	0,0023	0,0031
12	Cr	0,005	0,004	0,0035	0,002	0,003	0,002	0,002	0,0025	0,002	0,003	0,003
13	Ni	0,0027	0,0019	0,0023	0,0026	0,0026	0,0013	0,0017	0,0021	0,0027	0,0013	0,0021
14	Ga	0,001—2	0,001—2	0,001—2	0,001—2	0,002	0,001	—	<0,001	0,002	<0,001	0,001
15	Be	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

The results of ten spectral analyses are given in Table 2. 69 chemical elements were determined with different degrees of sensitivity. All of the metalloids were not determined, with the exception of phosphorus and potassium, which in the working region of the ISP-28 spectrograph yield lines of very weak intensity. Gallium was determined with lowered accuracy. Beryllium was determined semiquantitatively.

Examination of Results

As a whole, moldavites, as the analyses show, differ from indochinites by a greater acidic content: an increased amount of Si (40% against 34%), Ba (0.36% - 0.13%), Sr (0.06% - 0.03%), and Zr (0.03% - 0.009%). Concurrently typically "basic" elements are present in lessened amounts: Fe (1.5% instead of 3.7%), Mg (1.0% - 1.3%), Cr (0.003% - 0.015%), Ni (0.002% - 0.01%), V (0.003 - 0.008%), Ti (0.37% - 0.68%); Cu and Co, discovered in indochinites in quantities of 0.002% and 0.001% respectively, were not found in moldavites. The total of alkalines was practically the same in both groups, but in moldavites there is somewhat more K and correspondingly less Na.

Within the moldavite group notable variations are noted in composition (Fig. 1). Just as in the indochinites, the content of Ti oscillates sharply from 0.20 to 1.1%. In sample with stock No 1023 there is very much Ti, in No 1011 - much Ba, but little Sr and Zr, in No 971 - much Ti and little Mg, Sr, and Mn, in No 962 - little Ga, and so on. Some parallelism is established in the content of V and Ga.

Within the limits of one sample (stock No 19) the content of Cr and Mn varies particularly noticeably, and to a less degree - V, Ga, Ca, B, Na, Zr, Mg; the content of other elements remains practically the same.

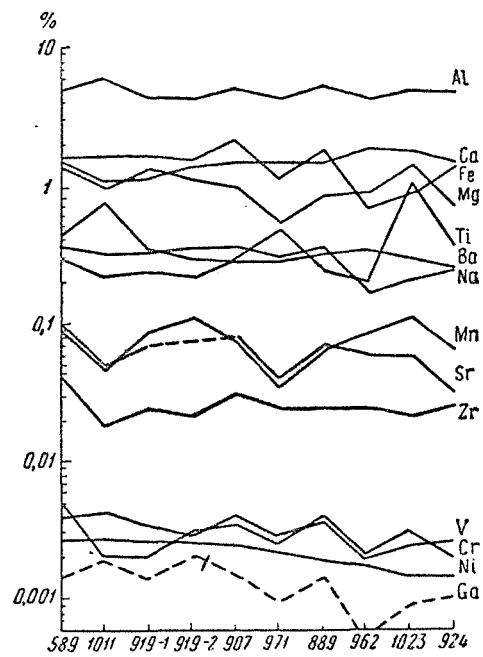

Fig. 1. Variations in the composition of moldavites

The characteristics of composition noted do not permit a direct correlation of moldavites with any terrestrial rock or with meteorites. Being typically acidic formations, moldavites differ greatly from normal earthly rocks in the content of several components and the ratios between them. Particularly noticeable are the discrepancies between Ca and Na, Ni and V, Fe and Ni, Fe and Cr, Ca and Mg, and so on. Good indicators of basicity are the ratios of three elements - V : Ni : Co. From acidic rocks to ultrabasic rocks and meteorites the value Ni : V changes 83 times, and Ni : Co six times. In this regard moldavites, notwithstanding their acidic character, approach basic and intermediate rocks, while indochinites, which with

a noted difference show much in common with moldavites, also approach ultrabasic rocks and meteorites.

Clmparing the possibility of the successive superposition on a normal acidic phase with 0.004% V, 0.0008% Ni, and 0.0005% Co of basic, ultrabasic and meteoritic matter, it is possible by mathematic computation to come to the conclusion that indochinites are closer to meteorites, while moldavites approach meteorites and ultragasics to the same degree.

Thus, in regard to terrestrial conditions tektites are a hybrid rock with an anomalous microelement composition that attest to the laying down of a basic (or meteorite ?) phase on an acidic one. Indochinites manifest this process especially strongly, moldavites somewhat more weakly. However, the data obtained does not invalidate purely cosmic theories for the formation of tektites, envisaging an extraterrestrial differentiation of the meteoritic substance. The question of the origin of tektites remains open for the time.

The detection of small globules in indochinites and moldavites has aroused great interest. If the frequency of their discovery (considerably more in the former, than in the latter) is related to the content of Ni and then correlate this with the presence of plessite globules in the silica glass of Vabara(?) and Henbury(?), it is possible to make far-reaching conclusions on the genesis of tektites. However, another point of view on the origin of these inclusions is possible: they could be the centers of primary crystallization of amorphous substance, with elements of ordered isomorphic endocryptic relationships of chemical elements. Thence, the noted regular relationship between individual elements, which in the case of complete crystallization will enter a lattice according to definite crystallochemical laws. Further microscopic investigations using the method of physicochemical enrichment should resolve this question.

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